NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 3087

EXPERIMENTAL INVESTIGATION OF TWO-DIMENSIONAL TUNNEL-WALL INTERFERENCE AT HIGH SUBSONIC SPEEDS

By Earl D. Knechtel

Ames Aeronautical Laboratory
Moffett Field, Calif.

Washington
December 1953

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 3087

EXPERIMENTAL INVESTIGATION OF TWO-DIMENSIONAL TUNNEL-WALL INTERFERENCE AT HIGH SUBSONIC SPEEDS

By Earl D. Knechtel

SUMMARY

The tunnel-wall interference for a two-dimensional-flow, rectangular, closed-throat wind tunnel has been investigated experimentally for the Mach number range from 0.3 to 0.9. The ratio of airfoil chord to effective tunnel height was varied systematically from 0.119 to 0.595 without affecting the test Reynolds numbers, which ranged from 0.9×10^6 to 1.8×10^6. Aerodynamic data obtained under these conditions for a model having an NACA 4412 profile, when compared with the corresponding data obtained essentially free of tunnel-wall interference, showed the influence of the walls to become progressively greater with increasing Mach number and with increasing chord-height ratio.

For ratios of airfoil chord to tunnel height up to approximately 0.15, tunnel-wall interference is small and correction by the small-perturbation theory yields satisfactory results. For larger values of chord-height ratio, wall interference becomes progressively greater and corrections by this method become increasingly questionable.

INTRODUCTION

The theory of wind-tunnel-wall interference for two-dimensional-flow, rectangular, closed-throat wind tunnels has been the subject of numerous investigations for both incompressible and compressible flows. Guided by the known exact solutions for incompressible flow, the wall-interference problem for compressible flow is conventionally treated by linearizing the differential equation of motion by the assumption that velocity perturbations due to the walls are small with respect to the stream velocity. Superposition of flows is then technically permissible within the limits of the small-perturbation assumption, and the resulting boundary-value problem may be readily solved by the method of images (refs. 1 and 2) or by more generalized methods (ref. 3).

Since the small-perturbation theory implies a restriction on the size of the model relative to the wind-tunnel dimensions, it is of practical interest to establish the limits of relative model size within which these theoretical tunnel-wall corrections are valid. The present investigation was undertaken to establish these limits for an airfoil section in a two-dimensional-flow, rectangular, closed-throat wind tunnel. The ratio of airfoil chord to tunnel height was varied systematically over a wide range of values, and the aerodynamic data obtained for these conditions were compared with corresponding data for the same airfoil tested at a chord-height ratio sufficiently small that the results were essentially free of tunnel-wall interference. Based on this comparison of experimental airfoil characteristics, the theoretical wall-interference corrections of reference 1 are examined over the test range of chord-height ratios at Mach numbers up to 0.9.

NOTATION

c airfoil chord

c_d section drag coefficient

c_l section lift coefficient

h tunnel height

M stream Mach number

P local pressure coefficient, $\frac{p_l - p}{q}$

p stream static pressure

p_l local static pressure

q stream dynamic pressure

α angle of attack

APPARATUS AND METHODS

The principal part of this investigation was conducted in the Ames 1- by 3-1/2-foot high-speed wind tunnel, which is of the two-dimensional-flow, low-turbulence type having a rectangular, closed test section.

The model employed in these tests was the 5-inch-chord NACA 4412 pressure distribution airfoil employed in the investigation of reference 4. A sufficient number of surface pressure orifices was used to permit accurate measurement of chordwise pressure distribution. The model was mounted across the 1-foot dimension of the test section, the model ends protruding through circular side-wall plates which had cutouts contoured for small clearance around the airfoil. Rubber gaskets prevented air leakage at these junctions of the airfoil with the wall. The circular side-wall plates were mounted in the tunnel walls in such a manner that they could be rotated to permit adjustment of the angle of attack, a gasket being provided at each sliding surface to prevent air leakage.

For these tests in the 1- by 3-1/2-foot wind tunnel the ratio of airfoil chord to tunnel height was systematically varied from 0.119 to 0.595 by maintaining a constant airfoil chord while varying the effective tunnel height, this method having the advantage of not affecting the range of test Reynolds numbers. The chord-height ratio 0.119 corresponded to the normal arrangement of the model in the full tunnel height of 42 inches. To obtain a chord-height ratio of 0.156 the tunnel height was reduced to 32 inches by the use of two wooden liners along the floor and ceiling of the test section. The two largest chord-height ratios, 0.357 and 0.595, were obtained by using two and four image airfoils to make the effective tunnel heights, respectively, one-third and one-fifth the normal height. These image models, of 1-foot span and set, in each case, to the appropriate angle of attack, were mounted at the tunnel walls in such a manner as to prevent air leakage between the model ends and the walls. Although use of such image airfoils to reduce the effective tunnel height may not duplicate exactly the boundary conditions of solid straight walls, these unknown effects are believed to be small in comparison with the effects of chord-height ratio being investigated. The four tunnel and model configurations are illustrated in figure 1.

To approach the condition of 0 chord-height ratio and thus provide almost interference-free data with which to compare the results of the above tests, the same 5-inch-chord NACA 4412 model was tested between two-dimensional walls in the Ames 16-foot wind tunnel ($c/h = 0.026$). This adaptation of the 16-foot wind tunnel to two-dimensional testing was made possible by the installation of two parallel 20-foot-chord walls which spanned the test section. The model was mounted so as to span the 18-inch channel between the walls in much the same manner as for the tests in the 1- by 3-1/2-foot wind tunnel. It is recognized that this necessity of testing in another wind tunnel to obtain data at a very low chord-height ratio may introduce some extraneous flow effects which, although unknown, are considered to be small.

For each value of the chord-height ratio, simultaneous measurements were made of chordwise pressure distribution and wake total-head distribution through an angle-of-attack range from -4° to $+6^{\circ}$. Lift and pitching moment were obtained by integration of the pressure distributions. For all the tests in the 1- by 3-1/2-foot wind tunnel, drag was determined by the method of reference 5 from the wake surveys. The drag-rake data obtained in the 16-foot wind tunnel was found to become unreliable at the higher Mach numbers due to choked flow between the drag rake and the side wall upon which it was mounted. For this reason, drag was determined in this case by adding a friction drag to the pressure drag obtained by integration of the pressure distributions. The friction drag coefficient was determined experimentally as 0.0055 within the range of Mach numbers for which the drag rake gave reliable results, and was assumed constant for all the tests in the 16-foot wind tunnel.

Mach number variation was from 0.3 to approximately 0.9 and the corresponding Reynolds numbers ranged from 0.9×10^6 to 1.8×10^6.

RESULTS AND DISCUSSION

The variation with Mach number of section lift coefficient at constant angles of attack is shown in figure 2 for five values of chord-height ratio, ranging from 0.026 for the essentially interference-free data obtained in the Ames 16-foot wind tunnel to 0.595 for the largest ratio investigated in the 1- by 3-1/2-foot wind tunnel. Figure 2(a) presents, for angles of attack of -4°, 0°, and 4°, lift coefficients and Mach numbers uncorrected for tunnel-wall interference. Comparison of these uncorrected results for the larger chord-height ratios with those for the interference-free case ($c/h = 0.026$) affords an indication of the amount of wall interference present through this range of Mach numbers and lift coefficients. Figure 2(b) presents these lift results as corrected for wall interference by the small-perturbation theory of reference 1. Comparison with the interference-free data here indicates the degree to which the theoretical corrections compensate for the wall interference indicated in figure 2(a) and allows some conclusions to be drawn regarding the range of chord-height ratio over which the small-perturbation theory may be considered valid.

For Mach numbers below the force break, figure 2(a) indicates that the wall interference is small for chord-height ratios up to approximately 0.2 but that it becomes significantly greater as chord-height ratios are increased beyond 0.2. Reference 1 presents data at low Mach numbers which exhibit essentially the same characteristics and which, in addition, demonstrate that, even for chord-height ratios up to 1.0, correction of lift coefficient and angle of attack by the linear theory brings results into reasonably good agreement with interference-free data. Although similar corrections applied to the data of the present investigation reduce the spread in the data due to tunnel-wall interference, the agreement in final results for various chord-height ratios (fig. 2(b)) is not as good as that shown in reference 1.

For Mach numbers above the force break, wall interference may cause a large reduction in the indicated Mach number for abrupt decrease in lift coefficient at a given angle of attack. In the present case (fig. 2(a)) this reduction in Mach number becomes progressively greater as the chord-height ratio is increased and as the angle of attack is decreased. When the magnitude of the wall interference is relatively small, the scatter remaining in the data after correction by the theory of reference 1 is small, as may be seen by comparing figures 2(a) and 2(b) for chord-height ratios up to 0.156. As an aid in choosing a limiting chord-height ratio below which correction of these data by the small-perturbation theory yields acceptable results, figure 3 shows this direct comparison of uncorrected and corrected data for chord-height ratios of 0.119 and 0.156 with the corresponding data obtained essentially free of wall interference. Based upon these results and upon the limits of acceptable accuracy, it may then be considered that for values of chord-height ratio below 0.15, lift coefficients and Mach numbers may be corrected satisfactorily for wall interference by the method of reference 1.

In figure 4, some pressure distributions are presented for a chord-height ratio of 0.119, both uncorrected and corrected, together with the corresponding pressure distributions obtained essentially free of tunnel-wall interference. These results indicate that correction by the small-perturbation method brings pressure distributions into better agreement, even at Mach numbers quite near choking.

The variation with Mach number of section drag coefficient at angles of attack of 0° and 4° is shown in figure 5 for the five chord-height ratios employed in these tests. It should be pointed out that for the three largest chord-height ratios, the drag rake used was such that it caused tunnel choking to occur at a Mach number somewhat lower than the choking Mach number dictated by the airfoil in the absence of the drag rake. Tests with and without the drag rake in place showed no significant change in airfoil pressure distribution due to the rake. Therefore, pressure distributions were obtained up to the choking Mach number determined by the airfoil itself, but for the three largest chord-height ratios drag could only be determined up to a somewhat lower Mach number.

Figure 5(a) presents the uncorrected drag coefficients and Mach numbers and provides an indication of tunnel-wall interference similar to that of figure 2(a), the magnitude of the wall interference increasing progressively with increases in either Mach number or chord-height ratio. In figure 5(b) the drag data are shown corrected for tunnel-wall interference by the method of reference 1, and again the trends are much the same as those shown by the lift data.

Thus, based upon the experimental lift, pressure distribution, and drag results, it is considered that, for chord-height ratios less than approximately 0.15, corrections for tunnel-wall interference at compressibility speeds are of the same magnitude as those predicted by the small-perturbation method.

CONCLUSIONS

The results of an experimental investigation of wall interference in a two-dimensional-flow, rectangular, closed-throat wind tunnel, through a Mach number range from 0.3 to 0.9 and a corresponding Reynolds number range from 0.9×10^6 to 1.8×10^6, lead to the following conclusions:

1. For ratios of airfoil chord to tunnel height up to approximately 0.15, tunnel-wall interference is small and results corrected by the small-perturbation theory are in satisfactory agreement with corresponding data obtained essentially interference free.

2. For larger values of chord-height ratio, wall interference becomes progressively greater and results corrected by this method become increasingly questionable.

Ames Aeronautical Laboratory
National Advisory Committee for Aeronautics
Moffett Field, Calif., Oct. 1, 1953

REFERENCES

1. Allen, H. J., and Vincenti, W. G.: Wall Interference in a Two-Dimensional-Flow Wind Tunnel, with Consideration of the Effect of Compressibility. NACA Rep. 782, 1944.

2. Goldstein, S., and Young, A. D.: The Linear Perturbation Theory of Compressible Flow, with Applications to Wind-tunnel Interference. R.&M. No. 1909, British A.R.C., 1943.

3. Baranoff, A. V.: Tunnel Correction for Compressible Subsonic Flow. NACA TM 1162, 1947.

4. Pinkerton, R. M.: Calculated and Measured Pressure Distributions Over the Midspan Section of the NACA 4412 Airfoil. NACA Rep. 563, 1936.

5. Heaslet, Max. A.: Theoretical Investigation of Methods for Computing Drag from Wake Surveys at High Subsonic Speeds. NACA WR-W1, 1945. (Formerly NACA ARR 5C21.)

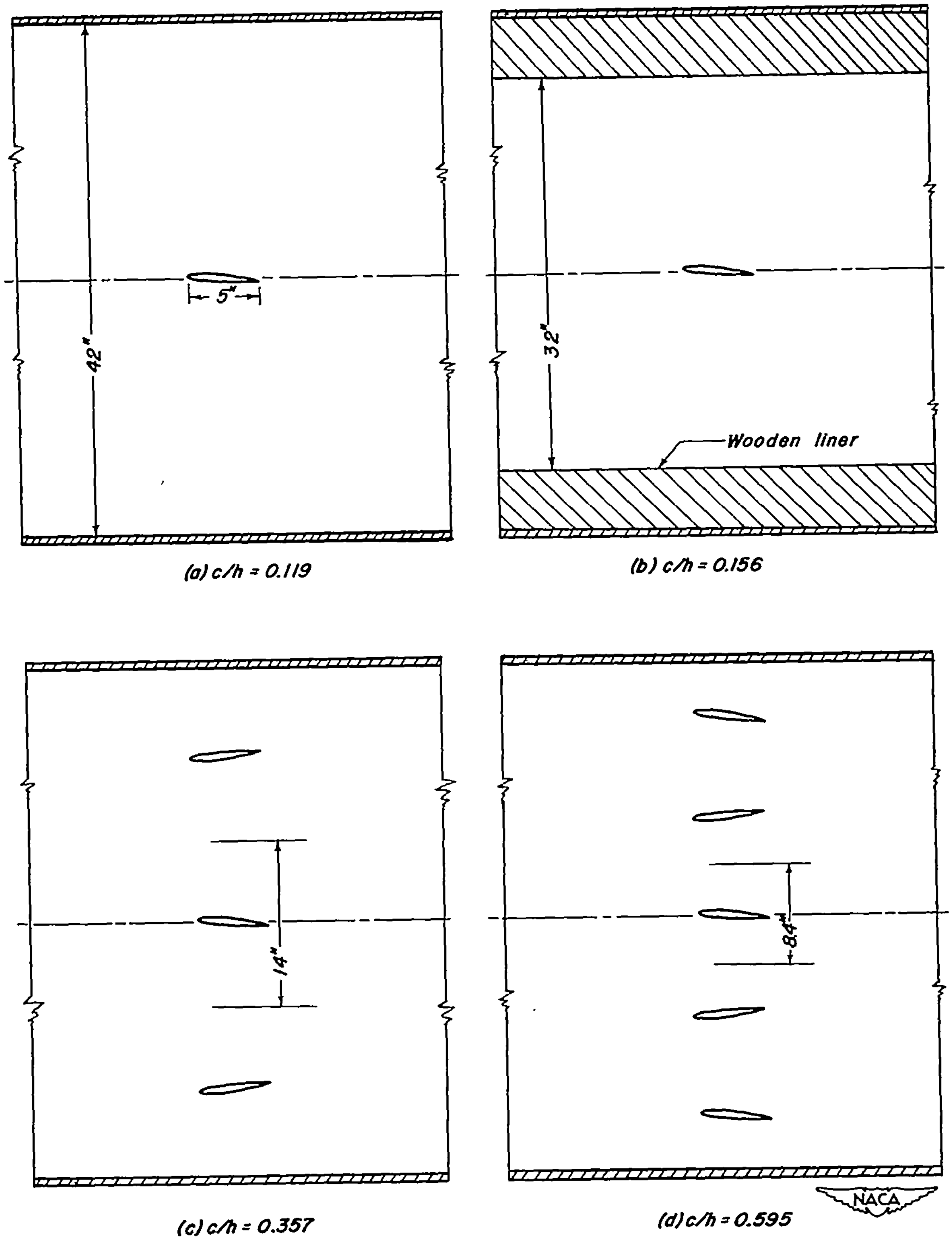
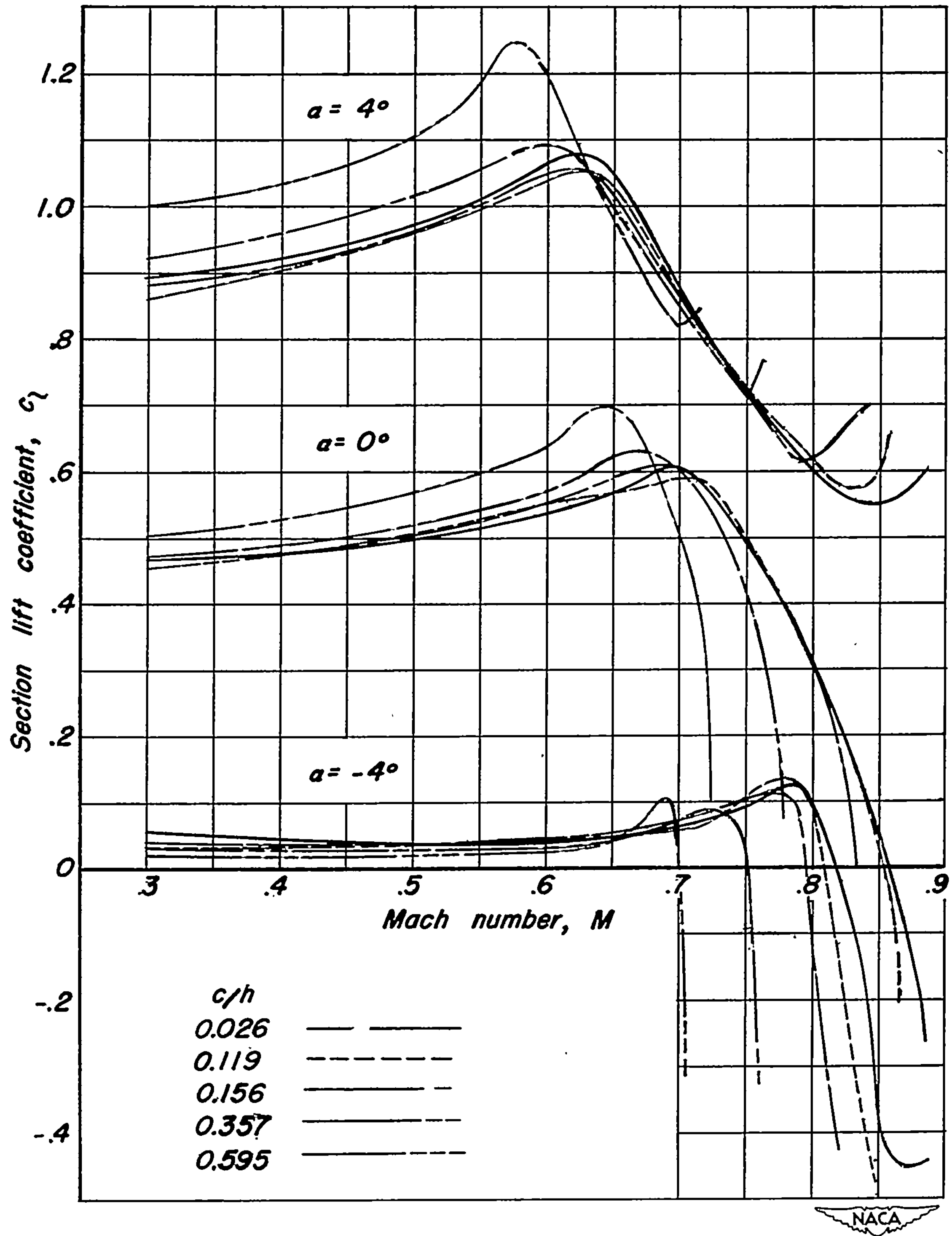
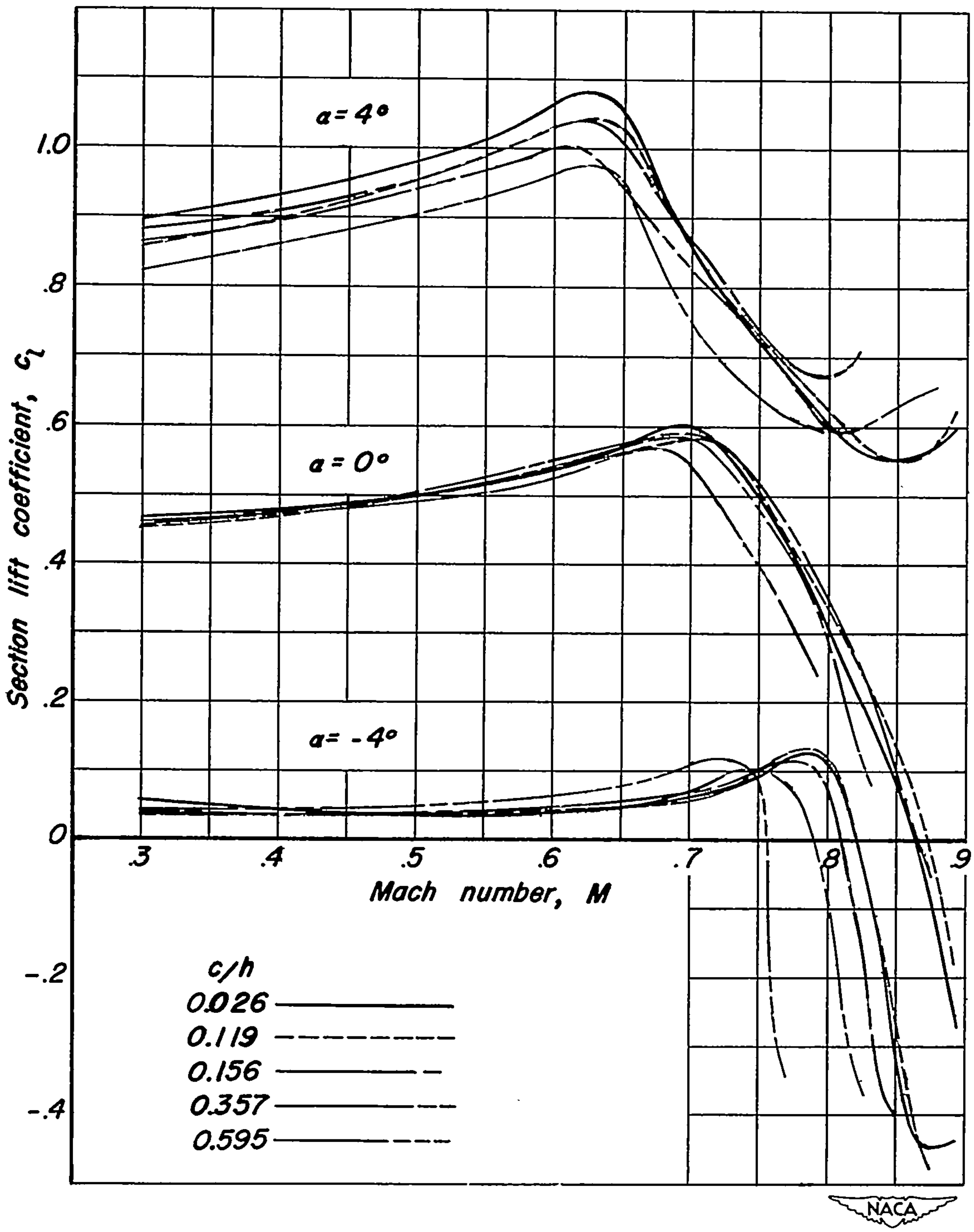


Figure 1.- Tunnel and model combinations used to vary the effective height of the 1- by 3-1/2-foot wind tunnel.



(a) Uncorrected for tunnel-wall interference.

Figure 2.- Variation of section lift coefficient with Mach number for several chord-height ratios.



(b) Corrected for tunnel-wall interference.

Figure 2.– Concluded.

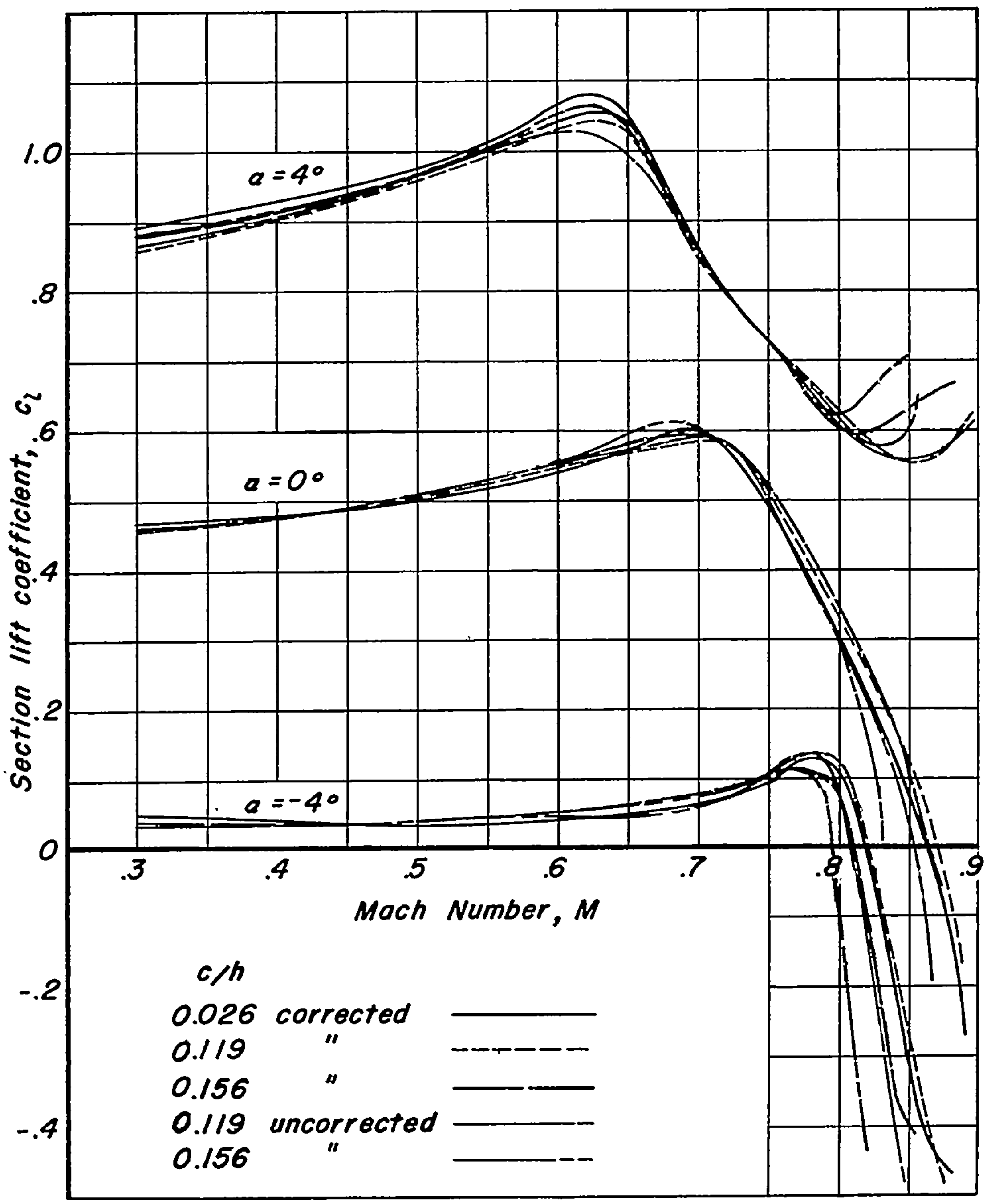


Figure 3.- Effect of wall interference and correction on the variation of section lift coefficient with Mach number.

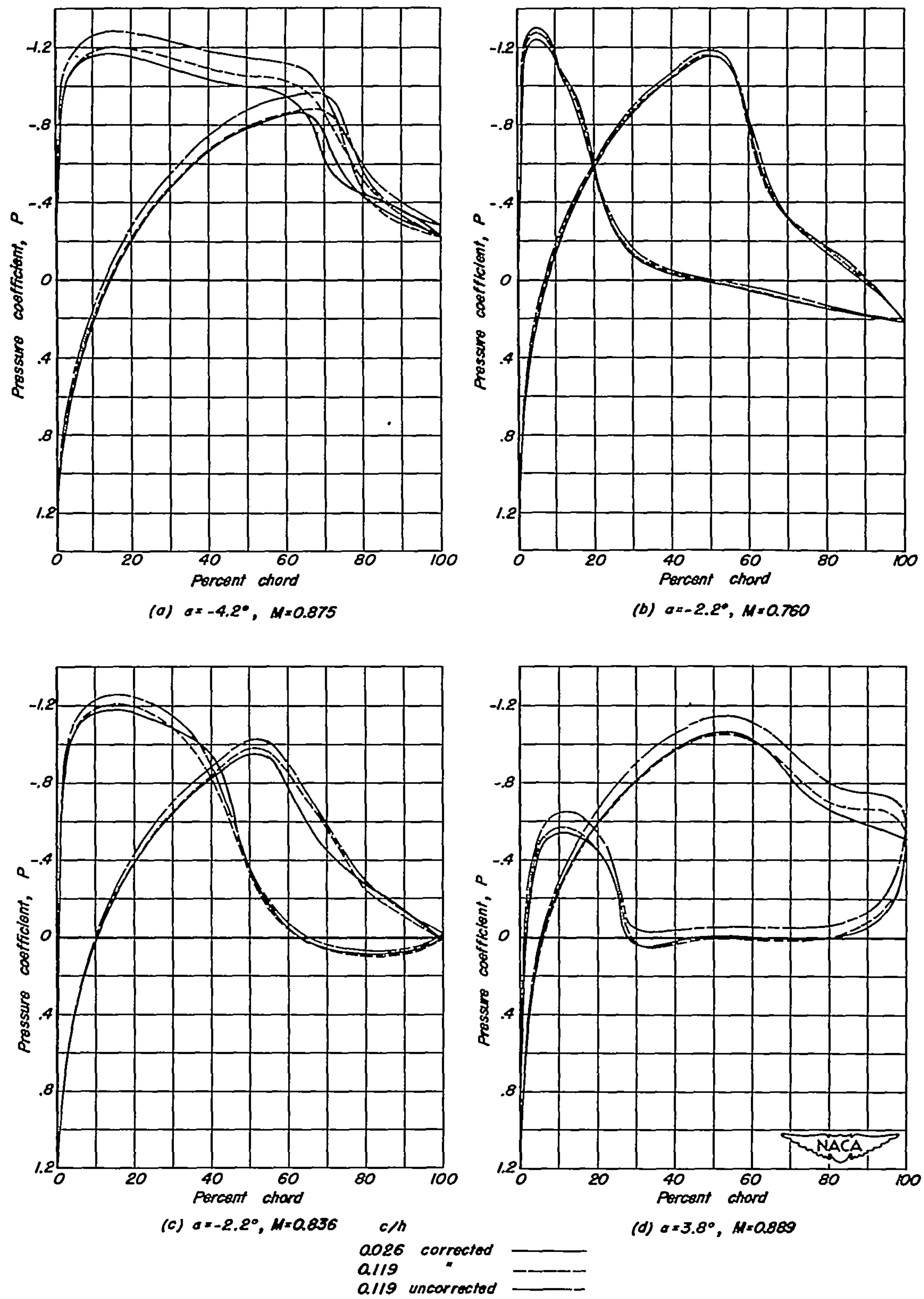
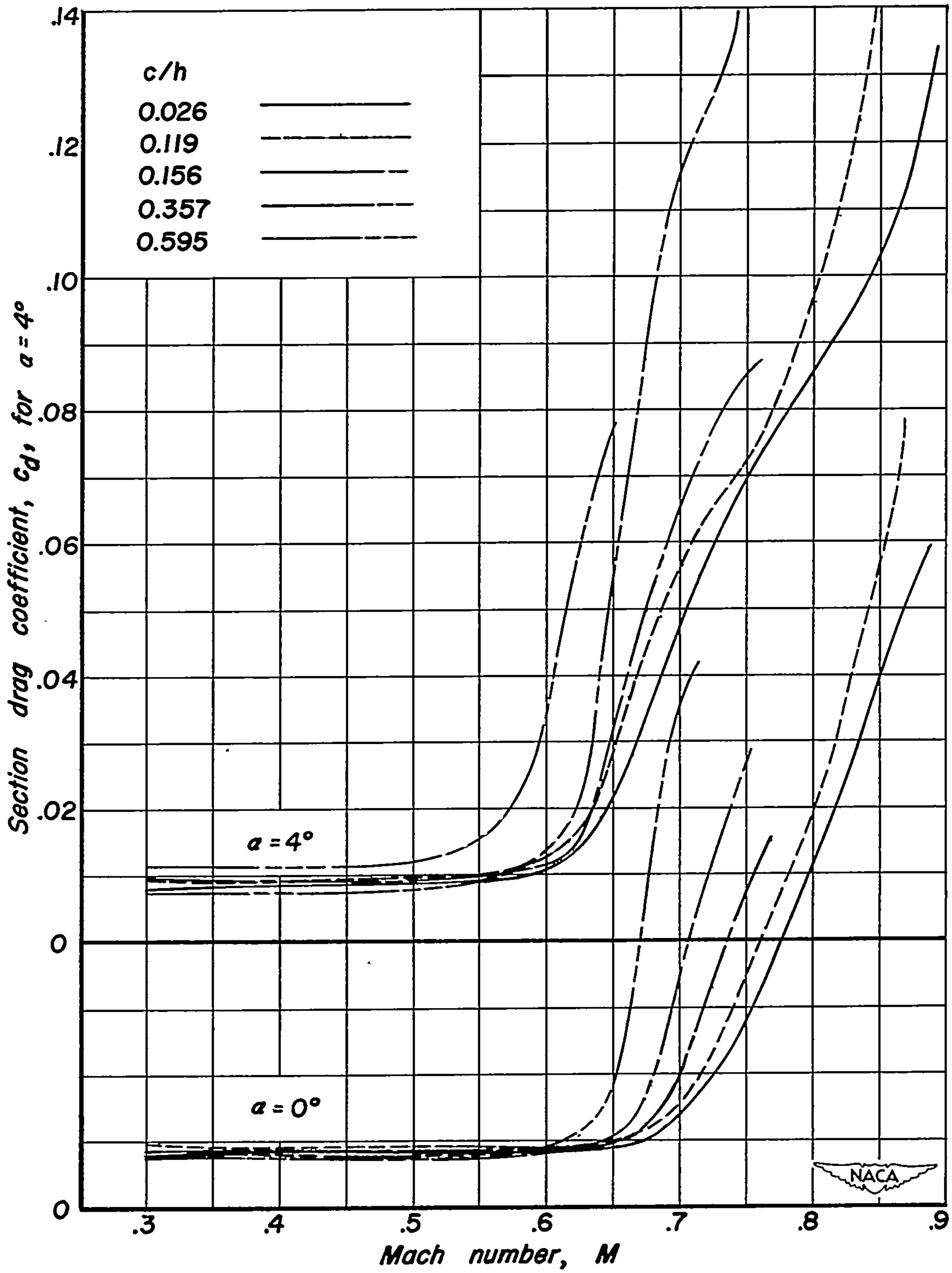
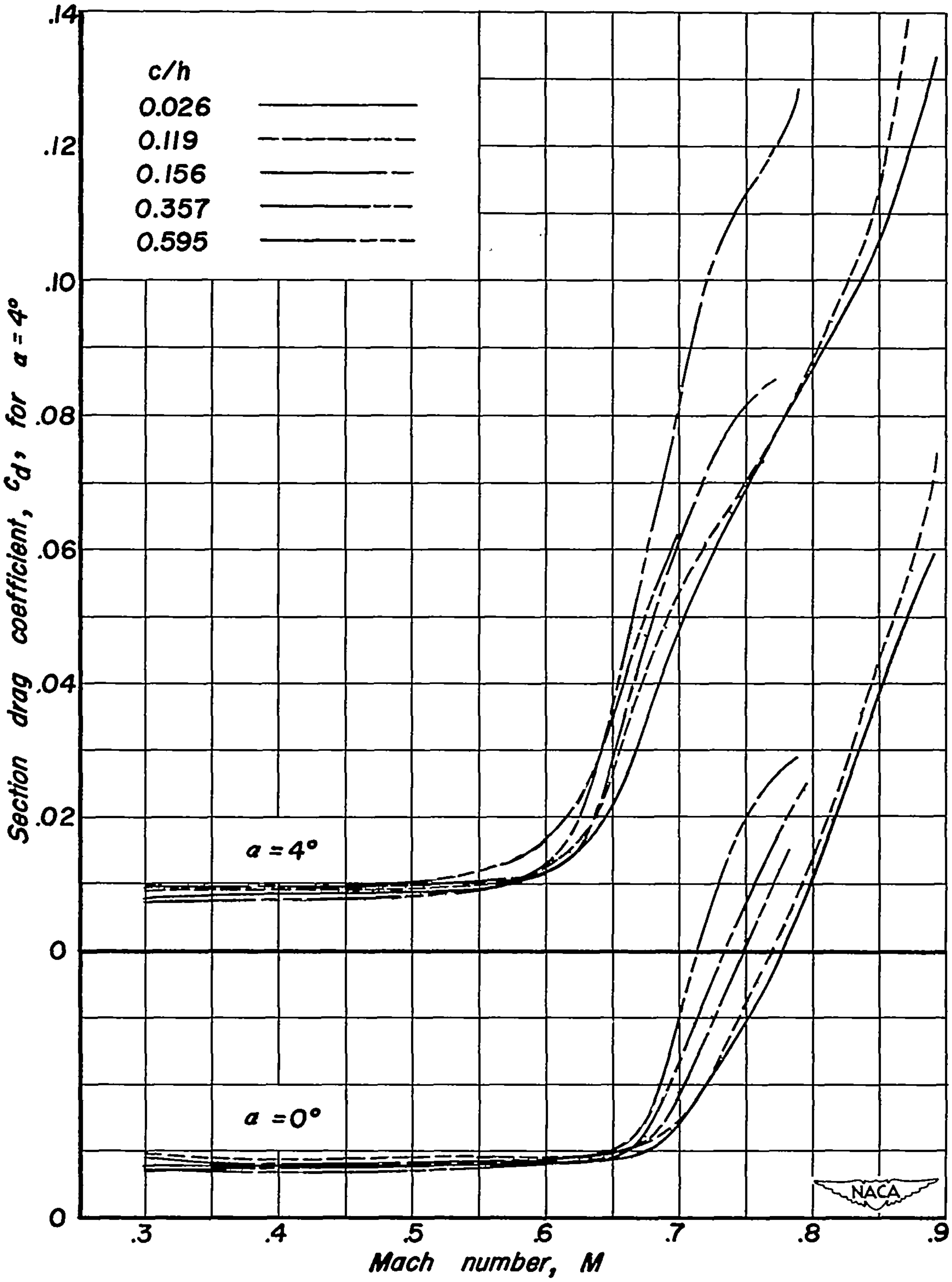


Figure 4.- Effect of wall interference and correction on airfoil pressure distribution for several angles of attack and Mach numbers.



(a) Uncorrected for tunnel-wall interference.

Figure 5. – Variation of section drag coefficient with Mach number for several chord-height ratios.



(b) Corrected for tunnel-wall interference.

Figure 5.– Concluded.

NACA-Langley - 12-15-53 - 1000